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Integrated modeling of agricultural production systems–Application to organic waste recycling

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Abstract

Recycling organic wastes in agriculture with controlled environmental impact has become a major stake for sustainable development. With this aim, our research is focused on building computer models for simulating organic wastes management scenarios and assessing their performances against agronomical and environmental criteria. Current achievements and future prospects of this endeavour are described in this presentation.

1 Context and motivations

Improving the sustainability of agriculture has become crucial to deal with tomorrow's challenges such as supplying food to a continuously growing world population while mitigating the environmental impacts. Recycling organic wastes to substitute chemical fertilizers for various organic products is one of the ways towards this end. Addressing this calls for the joint use of heterogeneous knowledge on both the biophysical (i.e. organic products, soils, crops) and managerial (i.e. farmers' practices) components of the whole production systems (single farms or groups of farms). Computer models, encompassing various pieces of knowledge, are hence built to represent these systems as linked production and consumption units spread over a territory. Two modelling approaches have been favored until now: hybrid dynamical systems, encompassing both continuous and discrete variables, and multi-agent systems.

2 Modelling and analyzing material flows on a territory

The driving thread of our research is a multi-step approach yielding successively:

1. Farm surveys, gathering data on the management situations found in the considered territory;
2. Farm typology, characterizing the main farming practices;
3. Conceptual models, synthesizing the knowledge gained from the surveys;

4. Computer models, simulating the interaction between the material flows and the farming practices;

5. Management scenarios assessed against agricultural and environmental criteria;

6. Tools or methods supporting stakeholders management.

Following this approach we developed:

- A conceptual representation of organic waste management practices by farmers [3];
- Material flow dynamic models to reason the management of livestock wastes within single farms [5, 9] or groups of farms [4]; the collective supply of a waste treatment plant [6]; the interaction of farming practices and biophysical flows in dairy farms [13]; the joint individual and collective organization of manure management on a territory [11];
- A modelling framework of human activity at operations level [8].

3 Conceptual modelling framework

The experience gained with the above cited livestock waste management models allowed us to devise, by generalizing their representational features, an 'Action-Flow-Stock' ontology [7]. Agricultural production systems are represented as a set of stocks connected by flows of materials controlled by the farming activities. Two types of flows are distinguished: "workable" flows, which take place only if there is human intervention, and "biophysical" flows, which take place even in the absence of human intervention. These flows interact through human activity, which aims at guiding the biophysical flows by the workable flows it generates. The management of the production system can thus be seen as the control of a set of stocks by the activities of the operator (i.e. the farmer).

4 'Planned' vs. 'situated' action

One of the questions we had to tackle was how to represent farming activities, i.e. human action in agricultural settings. The confrontation of action representation in the models based on our ontology (see above) with ontologies devised by other authors led us to question the paradigm of 'planned action' in favor of that of 'situated action' [12]. Altough the classical approach considers action as necessarily based on previously established plans (e.g. see [10]), many studies showed that, actually, most part of human behaviour needs no plan but, rather, stems from continuous local interactions between the agents and their environment. Our work, still in progress, is based on this paradigm [8, 1, 2]. As our goal is to represent large agricultural systems, basing any action on a plan appeared to us elusive, due to the complexity of both the production systems and the planning process itself. As we want to evaluate production systems, it is also by representing as better as possible what is 'actually' done, not what 'should' be done, that can allow the impacts of actual activities to be measured. It is, hence, the operational level our models strive to represent, focusing more on action than on decision and planning.

5 Assessing farming systems management

We distinguished between two aspects to be assessed in agricultural production systems: their technical performances and their environmental impacts. In the first case, modelling biophysical flows is needed to simulate their interactions with the workable flows. To do this, the knowledge on the biophysical processes is synthesized by expressions linking as simply as possible the most relevant causes and effects without going into a detailed description of the underlying mechanisms. In the second case, comparing different management strategies is needed. The issue of sustainable development leads us to think the impacts of these systems in terms of risk on other time and space scales (often larger) than those on which they were first considered. Hence, our interest in global assessment approaches, such as life-cycle analysis (LCA), which allows this comparison against different categories of impacts. An example of alternatively combining static LCA assessment with dynamic simulation assessment has been realized [11].

6 Management support using models

How to use simulation models to help agricultural stakeholders evaluate and design management strategies calls to practical questions on participatory simulation protocols and tools, likely to facilitate users' learning. Dealing with these questions was first attempted in 2004-2007, unfortunately with too little achievements. Simulation protocols, based on an experimental logic, were set to operate the dynamic simulation models listed above (§2). Although quite used by agronomists colleagues, these models have nevertheless never been tested truly to design management strategies with "real" agricultural actors in a participatory manner. This failure is mainly due to our poor ability to correctly grasp the social games of players in the organizational or political processes underlying the actual decision processes, particularly at a collective (territory) level.

7 Ongoing projects

Extending the representational power of our action modelling framework based on the situated action theory (see §4) is necessary to deal with huge and complex activity systems. Introducing concepts such as agent and space to represent coordination processes as well as the physical structure of work settings is underway [2].

Our farming systems assessment practices (see §5) also deserves to be rethought in the light of well-defined objectives: what has to be assessed, for which purposes, with which actors, on which space and time scales? Part of this questioning is a perspective currently being addressed by establishing a methodology to assess the impacts and services of organic wastes recycling on a territory scale. This work has been undertaken in the framework of an ongoing project [14] based, since its very beginning, on a participatory approach with the various stakeholders involved in the comprehensive management of organic wastes (agricultural, urban) in the west coast territory of Reunion Island.

One ambition of this project is also to evaluate how models could possibly be inserted into the collective process of designing new management options of these wastes, which will perhaps finally overcome the limitations pinpointed above (§6).

As the extension or reduction of model scopes is often sought, in particular to embrace larger territories, the choice of the 'scale of representation' of a production system becomes also an issue to be addressed, along with model scaling methods.

8 Conclusion

Summarizing, our main achievements are:

1. A methodology for modelling and analyzing material flows on a territory scale;
2. A conceptual modelling framework of farming systems;
3. A way of representing human activity in farming systems based on the 'situated action' theory.

Two issues still remain to be more thoroughly dealt with: assessing simulated management scenarios and using models with stakeholders to support actual management practices.

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